Dalmatian Toadflax, an Invasive Exotic Noxious Weed, Threatens Flagstaff Pennyroyal Community Following Prescribed Fire

BARBARA GOODRICH PHILLIPS and DEBRA CRISP

USDA Forest Service

Abstract: Many noxious weed infestations are initiated or increased by soil disturbance. With the recent emphasis on reintroduction of fire into natural ecosystems there has been increased interest in the effects of noxious weeds following fires. This paper discusses the effects of fire on Flagstaff pennyroyal, a Forest Service Region 3 sensitive plant, and the subsequent infestation of the project area by Dalmatian toadflax (*Linaria genistifolia* ssp. *dalmatica*).

Flagstaff pennyroyal (*Hedeoma diffusum* Greene) grows on Kaibab limestone soils adjacent to Flagstaff where forest restoration and fuel reduction projects are planned or underway. A prescribed burn study conducted on the Coconino National Forest from 1989 to 1995 showed that after burning, Flagstaff pennyroyal produced larger plants with more abundant flowers and had increased seedling recruitment and survivorship due to increased soil nutrients and reductions in duff, needle litter, and canopy closure.

During a follow-up reconnaissance of the Flagstaff pennyroyal prescribed burn area in 1999 we found that the burned area had been invaded by the noxious weed Dalmatian toadflax (*Linaria genistifolia* ssp. *dalmatica* [L.] Maire and Petitmengin), a member of the Figwort family (Scrophulariaceae). Recent post-fire vegetation studies in Southwestern ponderosa pine forests have shown dramatic increases in total cover of exotic plants in both moderate and high-severity burn areas (Crawford et al. unpublished data, Foxx 1996). In their studies of three 1996 wildfires in northern Arizona (Bridger Knoll, Pot, and Hochderffer), Crawford et al. found the highest cover of exotic species on the Hochderffer fire in high-severity burn areas. In both the Pot and Bridger Knoll fires, there was also an increase of exotic species in the moderately burned areas. The exotic plant cover occurred only in trace amounts in unburned patches.

Native to the Mediterranean regions of western Asia and Europe, Dalmatian toadflax is a fire-adapted species in its southeastern European homeland and has become prevalent on the Coconino National Forest, invading an estimated 80,000 ha. This perennial weed, found mainly in the northeastern and western United States and western Canada, was brought to the west coast of North America as an ornamental about 1874. The root system can reach a depth of 2 m or more; lateral roots can extend 3 m from the parent plant. Each plant can produce up to a half million seeds and it also produces vegetative root buds, each of which can produce a new and independent plant (Lajeunesse et al. 1995). When established, the plants are very competitive and difficult to eradicate.

Flagstaff pennyroyal is a small, prostrate, perennial member of the mint family (Labiatae) that is currently a U.S. Forest Service Southwestern Region (R3) sensitive species. It was nominated for listing as a threatened species with the U.S. Fish and Wildlife Service in the Federal Register on June 29, 1983. After further investigation (Phillips 1984, Boucher 1984), the species was found to be more abundant and more widely distributed than initially thought and listing was not warranted (Phillips et al. 1992). In 1984, the Coconino National Forest developed a management plan for Flagstaff pennyroyal (Boucher 1984) to mitigate potential problems that might occur due to management activities within its habitat.

Observations by various field personnel have suggested that increasing amounts of litter cover and tree canopy might be affecting the species ability to grow in certain places (Goodwin 1983, Fletcher 1984). A prescribed burn study conducted on the Coconino National Forest from 1989 to 1995 (Galeano-Popp 1989, Dudley 1989a, 1989b, Dudley et al. 1989, Phillips et al. 1992, Crisp 1997) had four objectives: (1) Determine whether any beneficial or adverse effects (increases or decreases in plant densities or vigor) occur in *Hedeoma diffusum* populations following fire treatment. (2) Assess the importance of fire intensity and fire timing

(season of burn) on *Hedeoma diffusum* plants. (3) Assess the effects of ground cover on the plants following fire treatment. (4) Evaluate the potential role of climatic factors on plants following fire treatments.

Methods

The prescribed burns were conducted in two comparatively flat and easily accessible sampling locations at the center of the Mormon Lake Ranger District on the Coconino National Forest (Dudley et al. 1989). The areas were selected because there were sufficient numbers of *H. diffusum* plants to provide for adequate samples for pre- and post-monsoon burn plots and controls with two densities of ground cover. Area 1 (A1) had a small amount of ground cover (5–30%). Area 2 (A2) had ground cover in the range of 10–53%. In Area 2, eight plots are located on a broad limestone ridge and two plots are 500 m disjunct to the northeast. Hot and cool intensity pre-monsoon, hot and cool intensity post-monsoon burn blocks, and control blocks were designated in areas 1 and 2.

We established two plots within each block in June of 1989. Each circular plot has a steel fence post at its center and a radius of 1.8 m. We took pre-burn samples in June, and we placed a galvanized nail adjacent to each plant found in the 20 plots. Fire lines were constructed around each 0.2–0.4 ha burn block to prevent the spread of the fire into the adjacent forest (Phillips et al. 1992). The plots were burned at the designated time and intensity. However, plots A1S4D2 and A2S3D3 burned cooler than planned. Therefore, the pre-monsoon hot burn in area 1 and post-monsoon hot burn in area 2 are represented by only one plot each, and the pre-monsoon cool burn in area 1 and the post-monsoon cool burn in area 2 are represented by three plots each (Table 1).

The plots were counted each year from 1989 through 1995. Each year different colored nails were used for new plants. Mortality was assessed based on the number of nails present without plants. This method of marking and counting plants was used until 1992. After 1992, plants were divided into two categories, adults and seedlings.

In 1999 we returned to the sites to locate the plots with a Global Positioning System unit, rephotographed each plot, and recorded the associated species and percent ground cover in each plot. At that time we noted that Dalmatian toadflax was invading several of the plots in Area 2. We organized a weed pull that summer and removed the stems only outside the plots within the immediate vicinity.

We decided to take this opportunity to investigate whether Dalmatian toadflax might have invaded the area, or existing populations of it within the area might have expanded, due to disturbances associated with the burn study. We also investigated whether the presence of Dalmatian toadflax in the plots appeared to have any correlation with the timing (pre- and post-monsoon) and intensity (hot and cool) of the burns. In August and September of 2000 we counted the number of Dalmatian toadflax plants within the invaded plots, and recorded the number of Flagstaff pennyroyal plants present in the Area 2 plots. We did not count the plants in Area 1 because only one Dalmatian toadflax was observed in Area 1 and it was pulled. We also walked the Area 2 fire lines to assess the spread of Dalmatian toadflax within and outside of the project area. We then looked for the presence of Dalmatian toadflax

Table 1. *Hedeoma diffusum* prescribed burn study plot design.

	Area 1 Low Ground Cover		Area 2 Medium Ground Cover	
Treatment	Plot number	Date burned	Plot number	Date burned
Pre monsoon hot	A1S4D1	5/16/90	A2S2D1	6/19/90
			A2S2D2	6/19/90
Pre monsoon cool	A1S3D1	5/16/90	A2S4D1	6/19/90
	A1S3D2	5/16/90	A2S4D2	6/19/90
	A1S4D2	5/16/90		
Post monsoon hot	A1S1D1	8/29/89	A2S1D1	10/30/89
	A1S1D2	8/29/89		
Post monsoon cool	A1S2D1	8/29/89	A2S1D2	10/30/89
	A1S2D2	8/29/89	A2S3D1	10/30/89
			A2S3D2	10/30/89

outside the project area to determine its overall distribution in the habitat and to evaluate whether it was present before 1989 or might have been brought in during the project burns.

Results

The numbers of total live *Hedeoma diffusum* plants for each year from 1989 to 1995 is shown in Table 2. Plant numbers generally increased during the study. However, the number of plants on some individual plots decreased. The hot burn treatments provided the greatest increase in plant numbers. However, when individual plots are examined, two plots had large increases in plants, whereas plant numbers on the other four plots actually decreased. The cool fire treatments provided more consistent increases until 1995.

An analysis of litter depth and tree canopy with habitat, burn intensity, and timing did not show any strong correlations (Crisp 1997). Needles cast from the trees stressed by the fires replaced the duff and needles consumed. Shallow roots and, in some cases, whole trees were killed by the hot fire treatments. Today many ponderosa pine trees are dead or dying from the stress of the fire treatments and drought, which will gradually expose the understory plants to more light and less needle litter over time.

The percent survival for each treatment is shown in Table 3. Percent survival in 1990 was most variable in the post-hot treatment (27–65%). Survival in the other treatments was generally higher, but still variable (post-cool 53–80%, pre-hot 63%, pre-cool 67–93%, and control plots 51–112%). Recruitment was generally low until 1992, when it increased dramatically on most plots . Recruitment ranged from 10% on one post-hot treatment to 89% on another post-hot treatment plot. The high rate of recruitment caused a large population increase in 1992. Recruitment was much lower on most plots in 1993 than in 1992, and then it increased in 1994 and 1995 on most plots. Most plots showed high survival in 1991, 1992, and 1994. Survival was lower in 1993 and 1995. Flagstaff pennyroyal plants in the burned areas were much larger and had many more flowers per plant than normal for several years after the burns.

The post-hot treatment and the pre-hot treatment mean percent increase in total live plants for 1989–1995 (Table 3) was 172% and 69%, respectively. The post-cool, pre-cool, and control treatments showed some increase from 1989 through 1995 but not as great. The post-cool mean percent change was 17%, the pre-cool had a 15% increase, and the control had a 6% increase.

The numbers of Flagstaff pennyroyal and Dalmatian toadflax present in the Area 2 plots in September 2000 are shown in Table 4. The numbers of

Table 2. Total live plants on *Hedeoma diffusum* fire plots, 1989–1995.

Treatment	1989	1990	1991	1992	1993	1994	1995
Post hot	170	111	112	703	398	460	463
Post cool	1036	899	1089	2209	1589	1242	1210
Pre hot	325	106	219	532	486	609	548
Pre cool	562	287	553	1876	775	822	645
Control	532	528	578	1083	1093	693	564

Pre and post refer to before and after monsoon rains.

Table 3. Mean percent change in *Hedeoma diffusum* fire plots, 1989–1995.

Year	Post hot	Post cool	Pre hot	Pre cool	Control
1989–1990	–34.71	–13.22	–38.96	–14.58	–0.75
1990–1991	0.90	21.13	106.60	92.68	–11.17
1991–1992	527.68	102.85	142.92	239.24	12.98
1992–1993	–43.39	–28.07	–8.65	–58.69	0.92
1993–1994	15.58	–21.84	25.31	6.06	–36.60
1994–1995	0.65	–2.58	–10.02	–21.53	–18.61
1989–1995	172.35	16.80	68.62	14.77	6.02

Pre and post refer to before and after monsoon rains.

Table 4. Observations of Flagstaff pennyroyal and Dalmatian toadflax in *Hedeoma diffusum* fire plots area in 1989, 1995, and 2000.

Plot	*Hedeoma* 1989	*Hedeoma* 1995	*Hedeoma* 2000	*Linaria* 2000	Notes
Post hot burn					
A2S1D1	86	48	23	0	disjunct
Post cool burn					
A2S1D2	79	8	35	0	disjunct
A2S3D1	76	48	32	0	
A2S3D2	90	73	82	0	
Pre hot burn					
A2S2D1	36	17	22	19	June burn
A2S2D2	126	110	66	6	June burn
Pre cool burn					
A2S4D1	167	99	82	18	June burn
A2S4D2	59	81	60	24	June burn
Control burn					
A2S5D1	108	83	19	18	
A2S5D2	195	205	76	0	

Pre and post refer to before and after monsoon rains.

Hedeoma diffusum plants in each of the plots had declined, in some cases substantially, from those recorded in 1989 and 1995. Dalmatian toadflax was noted as an associated plant species on some of the plots. The species had not occurred on the plots during the annual counts from 1989 through 1995. Five of the eight plots occurring on a ridge in Area 2 had been invaded by Dalmatian toadflax by September of 2000. Four of these infested plots (hot and cool) were burned on June 19, 1990. The infested control plot is immediately adjacent to infested pre-cool plots. None of the plots (hot or cool) that were burned after the monsoons on October 30, 1989 had been invaded by Dalmatian toadflax by September 2000.

By September of 2000 Dalmatian toadflax occurred on approximately 0.5 ha and extended east of the eight ridge plots to a site near the disjunct A2S1 plots. No Dalmatian toadflax plants were observed outside of the fire lines on the north, west, or south sides of the main project ridge where the native grasses and herbs are very dense. A couple of large mature toadflax plants were found below the ridge approximately 45 m west of the fire lines, growing under mature ponderosa pine trees.

Discussion

The invasion of Area 2 by the noxious Dalmatian toadflax was an unexpected result of this prescribed burn study. Steve Dudley (personal communication 2000) remembered seeing Dalmatian toadflax in Area 2 when conducting the June 1990 burns. He remembered that there were some toadflax plants on the eastern cliff-face below plots A2S4D1 and A2S4D2 (pre-cool) and A2S5D1 (control), and some plants in plot A2S2D1 (pre-hot). A photograph of fire ignition shows a Dalmatian toadflax present in plot A2S2D1, so there is also visual documentation.

Dudley's observations and the photograph were from June 1990, so it is unknown whether Dalmatian toadflax was present before any work was done in Area 2 or whether the noxious weed came in when the fire lines were established in late summer 1989 prior to the October burning. Some disturbance to the habitat would have occurred as the fire lines were scraped down to the mineral soil.

The start of this prescribed burn study was several years before noxious weed awareness and inventories were begun on the Coconino National Forest. However, some practices were followed in implementing the prescribed burn study that are considered important for noxious weed prevention (Phillips et al. 1998). Vehicles were parked on the road south of the project area; no vehicles were allowed to drive across the meadow below the plots. Shovels and chain saws were used to establish the fire lines. No heavy equipment such as bulldozers was used (Dudley, personal communication 2000).

All of the plots (hot and cool) burned in mid-June have become infested by Dalmatian toadflax whereas none of the plots (hot or cool) burned after the monsoons in late October have been invaded. This could indicate that timing of the burn is a more important factor than intensity of the burn for seedling establishment. Adult Dalmatian toadflax responds positively to fire because root buds are not killed and removal of top growth can stimulate production of vegetative shoots (Sheley and Petroff 1999).

According to Sheley and Petroff (1999), Dalmatian toadflax seedlings are vulnerable to dehydration and competition from other species and have difficulty getting established. They are easily outcompeted by plants in areas with good groundcover, and in particular by well-adapted perennials (Robocker 1970). This could explain why the Dalmatian toadflax has not yet invaded the areas surrounding the burn study area where the grasses are very dense.

The enhanced seedling recruitment and increased vigor of Flagstaff pennyroyal plants observed in this study support the belief that this rare plant is adapted to a frequent fire regime. Monitoring (U.S. Forest Service unpublished data, Crisp 1997) has shown that the Flagstaff pennyroyal is a short-lived perennial, with most plants living for 5 to 8 years. This is similar to the fire recurrence interval proposed for the ponderosa pine forests in the Flagstaff area (Swetman 1990, Sackett et al. 1994 a, 1994b).

Extreme drought conditions also affect Flagstaff pennyroyal survival. Most of the years from 1989 to 1995 had normal or above normal precipitation and the numbers of plants in the plots were still quite high at the end of the study. The year 1996, however, was one of the worst drought years on record (Crisp 1997), and the winter of 1999–2000 was also very dry. By August of 2000 there were substantially fewer Flagstaff pennyroyal plants in 9 of the 10 plots in Area 2. Three of the five permanent *Hedeoma diffusum* plots that were monitored in 1985, 1989, and 1996 (Boucher 1984) showed substantial decreases in plant numbers by June of 1996. One exposed plot located on a large limestone slab in full sunlight had declined by 99 percent (U.S. Forest Service unpublished data, Crisp 1997).

This prescribed burn study illustrates that urban interface and forest restoration efforts to reduce the risk of catastrophic fire could expand noxious weed infestations toward the outlying forests, which currently are less disturbed and less infested with noxious weeds. Several noxious weed species, including yellow starthistle (*Centaurea solstitialis*), diffuse knapweed (*Centaurea diffusa*), Scotch thistle (*Onopordum acanthium*), Mediterranean sage (*Salvia aethiops*), bull thistle (*Cirsium vulgare*), and others, in addition to Dalmatian toadflax, are expanding explosively in northern Arizona, especially in the urban interface (Crawford et al. in review, Griffis et al. 2001, Moser and Phillips 2000). Unless appropriate preventative and control measures for noxious weeds are undertaken during the urban interface and forest restoration efforts, noxious weeds could cause serious impacts to the biodiversity of these ecosystems.

According to recent literature and research on fire and exotic species (D'Antonio 2000, Foxx 1996, Crawford et al. unpublished data), fire in most ecosystems tends to promote rather than discourage introduced species, including in many ecosystems where fire has been an important force prior to European colonization. Research on the effects of fire in rare plant habitats must address invasive plants before these treatments are used on a landscape scale in ponderosa pine ecosystems (Moir, personal communication 2000, Neary et al. 2001).

Acknowledgments

Greg Goodwin provided the initial observations and ideas for both the fire study of *Hedeoma diffusum* and the initiation of the noxious weed program on the Coconino National Forest. Renee Galeano-Popp, Heather Green, and Steve Dudley were instrumental in developing the *Hedeoma* burn project and conducting pre-burn and initial monitoring. The Mormon Lake Ranger District fire crew conducted the burns. Numerous Forest Service personnel and volunteers read the plots each year. Laura Moser, Will Moir, and Julie Crawford provided ideas and discussions about the effects of various burn intensities on the spread of noxious weeds.

Literature Cited

Boucher, P. F. 1984. Management plan for *Hedeoma diffusum* Greene. Elden, Flagstaff, Mormon Lake and Sedona Ranger Districts, USDA Forest Service.

Crisp, D. 1997. Prescribed fire effects on Flagstaff pennyroyal (*Hedeoma diffusum* Greene): An independent study project for Northern Arizona University. Manuscript on file at USDA Forest Service, Coconino National Forest Supervisor's Office.

D'Antonio, C. M. 2000. Fire, plant invasions and global changes. In H. A. Mooney and R. J. Hobbs, eds. Invasive species in a changing world. Island Press, Washington, D.C.

Dudley, S. 1989a. U.S. Forest Service Southwestern Region prescribed burning plan for *Hedeoma diffusum*. USDA Forest Service, Coconino National Forest, Mormon Lake Ranger District.

Dudley, S. 1989b. Biological evaluation for threatened, endangered and sensitive species – *Hedeoma diffusum*. USDA Forest Service, Coconino National Forest, Mormon Lake Ranger District.

Dudley, S., R. Galeano-Popp, G. Goodwin, M. King, B. Monday, J. Nelson, K. Rethlake, and J. Tucker. 1989. Implementation plan for Flagstaff pennyroyal (*Hedeoma diffusum*) trial burn project. USDA Forest Service, Coconino National Forest.

Fletcher, R. 1984. *Hedeoma diffusum* status report supplement. USDA Forest Service, Albuquerque, New Mexico.

Foxx, T. S. 1996. Vegetation succession after the La Mesa fire at Bandolier National Monument. USDA Forest Service General Technical Report RM-GTR 286:47–69.

Galeano-Popp, R. 1989. Trial burn project plan for *Hedeoma diffusum*. USDA Forest Service, Coconino National Forest, Mormon Lake Ranger District.

Goodwin, G. 1983. Proposed Thomas and Walnut timber sales, Mormon Lake District, Coconino National Forest: Survey results and interim management guidelines for *Hedeoma diffusum* Greene. USDA Forest Service, Coconino National Forest, Arizona.

Griffis, K. L., J. A. Crawford, M. R. Wagner, and W. H. Moir. 2001. Understory response to management treatments in northern Arizona ponderosa pine forests. Forest Ecology and Management. In press.

Lajeunesse, S. E., P. K. Fay, D. Cooksey, J. R. Lacey, R. M. Nowierski, and D. Zamora. 1995. Dalmatian and yellow toadflax: Weeds of pasture and rangeland. Extension Bulletin 115. Montana State University Extension Service, Bozeman.

Moser, L. P., and B. G. Phillips. 2000. Final report to National Fish and Wildlife Foundation: Coconino National Forest (AZ) Weed Control Project No. 99-098-017.

Neary, D. G., W. H. Moir, and B. G. Phillips. 2001. Harvesting-related soil disturbance: Implications for plant biodiversity and invasive weeds. In Bioenergy from sustainable forestry: Principles and practice. Proceedings of the International Workshop: October 16–20, 2000, Coffs Harbour, New South Wales, Australia.

Phillips, B. G. 1984. Field survey for *Hedeoma diffusum* Greene, Coconino National Forest. Report submitted to USDA Forest Service, Coconino National Forest, Arizona.

Phillips, B. G., H. Greene, S. Dudley, and R. Galeano-Popp. 1992. Prescribed fire research on Flagstaff pennyroyal (*Hedeoma diffusum* Greene). In R. Sivinaki and K. Lightfoot, eds. Proceedings of the Southwestern Rare and Endangered Plant Conference, pp. 162–169. New Mexico Forestry and Resources Conservation Division, Energy, Minerals and Natural Resources Department, Santa Fe.

Phillips, B. G., T. Matza, and C. Christensen. 1998. Noxious weeds strategic plan working guidelines: Coconino, Kaibab and Prescott National Forests. Unpublished document, USDA Forest Service.

Robocker, W. C. 1970. Seed characteristics and seedling emergence of Dalmatian toadflax. Weed Science 18:720–25

Sackett, S., S. Haase, and M. G. Harrington. 1994a. Lessons learned from fire use for restoring Southwestern ponderosa pine ecosystems. In W. W. Covington and L. F. DeBano (tech. coords.). Sustainable ecological systems: Implementing an ecological approach to land management, pp. 54–61. USDA Forest Service General Technical Report RM-247. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Sackett, S. S. Haase, and M. G. Harrington. 1994b. Restoration of Southwestern ponderosa pine ecosystems with fire. In W. W. Covington and L. F. DeBano (tech. coords.). Sustainable ecological systems: Implementing an ecological approach to land management, pp. 115–121. USDA Forest Service General Technical Report RM-247. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Sheley, R. L., and J. K. Petroff, Eds. 1999. Biology and management of noxious rangeland weeds. Oregon State University Press, Corvallis.

Swetnam, T. W. 1990. Fire history and climate in the Southwestern United States. In J. S. Krammes (tech. coord.). Effects of fire management of Southwestern natural resources, pp. 6–17. USDA Forest Service General Technical Report RM-191. Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado.